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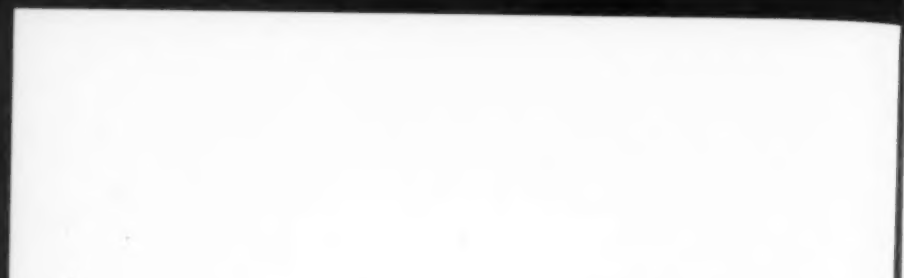
ERRATUM SLIP.

KNOCK-RATING OF EXPERIMENTAL FUELS OF OVER 100 O.N.—THE 17° MOTOR METHOD.

In paragraph 3 of this method, (I.P.—43/42) as published in the 5th Edition of "Standard Methods," the apparatus and procedure required are those set out in I.P.—44/44. This is in error. Apparatus and procedure required are those described in I.P.—44/42.



Vol. 30. No. 249. September 1944.

MOUNTAINS AND OIL.

By J. V. Harrison.

It may be of interest to review some features of geography with an object of investigating what connection, if any, there may be between mountain ranges and oil production or discovery. Any map of the world showing the principal physical features and the exploited oilfields puts one aspect of the question before us. Perhaps the most notable fact which emerges is that there are great areas of land without mountains and without any oil at all, like the bulk of the African and Australian continents. They are lands of plains and plateaus, where mountains are confined to a narrow margin. The Baltic Region, including all but the west of Scandinavia, much of Siberia and adjoining provinces of China, the north-east of North America and the north-east of South America are also areas of plateaux or plains formed by the wearing down of areas of old rocks, and from them no oil has been won. If the high mountains themselves be examined, with one exception at Lake Titicaca, it will be seen that oilfields do not occur *in* them. It is in the intermediate lands between the mountain crest and the naked rumps of the old plains and plateaux that the deposits of petroleum must be sought, and they are found in nearly equal numbers along the flanks of the mountain ranges and amidst the low hills and plains extending far away from them.

About 70 per cent. of the world's surface is covered by oceans, and the emergent land forms the other 30 per cent. First, the barren plains of old rocks, where no oil is, make up about 25 per cent. of this total. Their foundations of twisted, hardened ancient rocks, long since worn smooth by wind, water, and ice, have not been swamped extensively by the sea during the last 500 million years, and hardly any sedimentary deposits overlie them. Next, the main plains and the low sporadic hills associated with them, from which about half the world's production has been won, make up about 65 per cent. of the land area. These regions have often been covered by the sea, but they have risen gently above it from time to time, and the waters have ebbed back, leaving dry land, which sometimes became desert temporarily. In these areas sediments have been freely deposited as packets which may be a fraction of a mile or as much as 3 miles thick. The strata are usually well consolidated and upon the outer skirts of the old cores lie all but undisturbed. Farther away from these shields of old rocks the sediments are often warped, and, in a few cases, gently or even strongly folded.

Last, the mountain belts make up no more than 10 per cent. of the total land, but they contain about 50 per cent. of the world's oil. They are long, narrow strips of country where deposits have accumulated during many marine incursions to a thickness of usually 3 miles or more, and occasionally to as much as 10. These strips have long been restless. Their sediments have been compressed and folded in several stages, whilst their centre may have been punctured by masses of eruptive rocks like

granite. In many cases the compression affecting these zones has been sufficient to produce a suite of large and relatively regular folds in the beds, but in others the compression has been much more intense, giving rise to so great a humping up of the outer rocks of the crust that the ridge has grown higher than the mechanical strength of the rock materials can support. Part has had to slip aside, until the height has been reduced sufficiently to again ensure mechanical equilibrium—that is to say, until the rocks will stand up themselves without further sagging or bursting. Some of the excess load seems to have slipped off by a kind of flowage, for, given time, many bodies of sedimentary rock seem to act as if relatively plastic, and some to have been squeezed out from near the base on the flanks. Complicated flow sheets of both types are clearly exposed in many sections of certain well-known mountains, like the Swiss Alps. They are far too disturbed and have travelled far too uncomfortably to contain oil themselves, but they overlie a platform not nearly so churned up which may still retain its oil. This flight from earthly exaltation

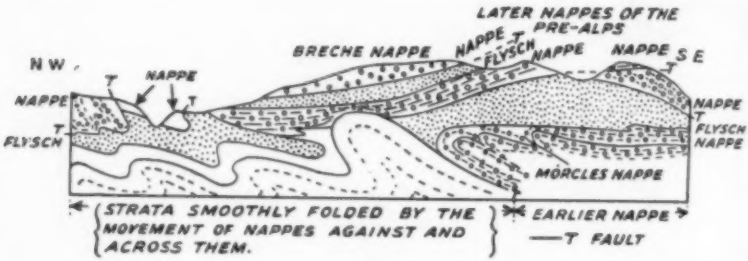


FIG. 1.

FLOW SHEETS N. OF THE SWISS ALPS AFTER A. LILLIE.

experienced by large packets of rock in the very tightly compressed mountains has produced a marked effect on the postures of the rocks below, and has given rise to structures in them very like those encountered in the belts of moderate mountain-building (Fig. 1). Wrinkled structures in the strata, however they may have been produced, may be satisfactory for the accumulation of oil, and it is in zones of undulations that the search for oil has been most logically and successfully conducted by geologists. The area of such zones in the mountain belts does not amount to more than 3 per cent. of the total land surface.

Very little is known about the swamped 70 per cent. of the earth's surface, but some parts of it have been surveyed in detail, and show that at least portions of the sea-floor are scored and uneven like the land surface. Mountain ranges rise from the ocean bed, and parts of them protrude above the sea level, furnishing chains of islands, some long and straight, some gently and some sharply curved, and some mere dots above the face of the waters. Examples are provided by the Dutch East Indies and the Antilles of the West Indies, by the Aleutian Islands or the group of islands making up Japan or the Philippines, and perhaps by the Antarctic Islands east of Cape Horn, including South Georgia, the Sandwich Islands, South

Orkney, and South Shetland Islands. All of these are akin in structure, being formed in part of strongly folded sedimentary rocks and in part of volcanics. Other submarine ridges exist, also worthy of the name of mountain, but made up wholly of volcanic rocks. A fine example is located in the mid-Pacific. It is 1600 miles long, with Midway Island at its western end and Hawaii at its eastern. Another great submarine range the composition and structure of which are still somewhat obscure follows a curving course for more than 6000 miles aligned roughly north and south in mid-Atlantic. Other mighty ranges have been discovered in the Indian Ocean between Socotra and Chagos Islands, with a spur running north towards Karachi. In addition to these chains of mountains, long, narrow troughs have been located crossing the sea-floor which cannot be matched by land features. The narrow ocean deeps appeal to the imagination, perhaps as the home of mysterious sea-serpents and other monsters, perhaps because the dents are deeper (35,400 feet) on the earth's surface than its biggest peaks are high (29,000 feet), and perhaps as the birthplace of some oil. Some of these great hollows lie close to elevated land masses like western South America, some close to sunken lands just covered by the sea, as between New Zealand and Tonga, and the deepest of all to the chains of islands forming Japan and the Philippines.

After this brief review of world geography we may consider what part mountains play now or have played in the past. Their principal rôle at present is that of barriers. They intercept free movement of peoples, animals, plants, and winds. The winds in turn play a vital part in the control of climates. The Alps separate the colder, wetter germanic plains from the milder, drier one of Italy. The winters of Poland are more severe than those of the Hungarian plains across the Carpathians. The bitter extremes of the Russian steppes are not shared by Mesopotamia across the Zagros Ranges, nor those of Kashgar and Lop Nor by the Indo-gangetic plain south of the Himalayas. There is also a tremendous difference in rainfall between desertic Central Asia and monsoon-soaked India. In the New World, where the ranges run more nearly north and south, a comparison is possible between places at the same latitude but on the opposite sides of the water-shed, and again the differences are enormous. For instance, they occur between foggy Vancouver and dusty Winnipeg; green San Francisco and brown Salt Lake City; equable Los Angeles and El Paso with its large diurnal variation. Where the continent narrows to an isthmus noteworthy differences still obtain, as between Colima and Tuzpan, or Santa Cruz and Vera Cruz in Mexico; between San José and Puerto Berrio in Guatemala; and between Punta Arenas and Puerto Limon in Costa Rica. There is not so much difference across the knot of ranges in Colombia and Equador, but farther south the contrast again becomes acuter between the guano coast of Peru and the steamy rain forests of the Amazon; between the nitrate coast of Chile and the idyllic valleys of Mendoza; and between the cold rain forest of the Chilean fiords and the grassy pampas of Patagonia in Argentina.

The sunken ranges are obstacles as well, although they may have small effect on climate. They arrest the flow of ocean currents, so that basins on opposite sides of them may contain water in different degrees of aeration. Adequate aeration seems to be the vital factor in deciding the state of

what are called normal marine deposits. In basins where free circulation is prevented, the lower layers of water may become stagnant, and then sulphuretted hydrogen develops. In this environment the sediments form fœtid and slimy, and, according to one school of thought, it is here that potential oil is most likely to be turned into the real thing. The northern part of the Indian Ocean is divided up by submarine ranges into three basins : the Gulf of Oman in the north-west, the Arabian sea in the north-east, and the Somali basin in the west. The first is collecting green mud in the shallower part and, whilst rich in sulphuretted hydrogen, is almost devoid of life; the second contains a coating of red clay with manganese-rich nodules and has no animal life in its depths; and the third is the gathering ground of a deposit of globigerina ooze with prolific marine life. A recent investigation provided these examples of the effect of sunken ranges.

Another function the mountains perform is to offer themselves as the easiest victims of erosion, and because they bar the passage of the winds, they forge the knife for their own sacrifice in the shape of the rain which falls in special concentration upon them. This carries away the mantle of decay, the soil which would provide the solid rock with a defensive sheath against further depredations of the weather. The amount that is worn off the opposite sides of a range may differ greatly, depending primarily on the rainfall, but the distance from the sea determines whether gravel, grit, sand, silt, or clay actually reaches the ocean. The mountains often provide the immense volume of sediment suspended in river water, but as the study of sedimentation progresses it becomes clear that, particularly in the shallower inland seas like the North Sea, the constitution of the neighbouring countries plays an important part in determining the constitution of the sediments. Adjacent exposures of sandstone make for abundant sands in the pan of the local sea, and many outcrops of schist or shale for predominant mud. In the open sea near shore, the effect of climate, frigid, temperate or hot, arid or humid, plays a part, but this is masked or overwhelmed when a big river discharges near by. It virtually monopolizes the building up of the column of strata. Great differences exist between deposits near to land or " within soundings " and those far away at depths greater than 10,000 feet. The former are much thicker, and, being derived from land, are more abundant and more varied than the latter. They are fresher and lighter coloured than their neighbours out to sea, which are largely formed of dust-blown fragments and skeletons of floating marine organisms. They are more freely endowed with carbonaceous organic matter than the deep-sea deposits.

Geologists still argue about the origin of oil and the kind of conditions most suitable for its formation, but most of them are prepared to admit that oil, potential or actual, is a sediment or part of a sedimentary series. Oil deposits usually occur where deposits are thick, and some of the most prolific are encountered where the sediments are thickest. Oil is not known where there is no development of strata, and it is inferred that the greater the thickness of the beds the greater the chance of finding some oil. The geosynclines, the long, relatively narrow oceans of former times, were troughs in which detritus came from two sides, and were, in addition, avenues across the surface of the earth in which limestones were

built up with unusual facility. They were the sumps into which the thickest columns of beds have been packed, but at the present time it is difficult to find an example on the face of the earth. The only existing feature which remotely resembles a geosynclinal sea is that between the Sunda shelf on the north-west, made up of Borneo, Sumatra, and the shallow nearly level floor of the Java Sea, and the Sahul shelf on the south-east, made up of a submarine platform skirting the north coast of Australia and the west coast of New Guinea. Some of the Dutch geologists maintain that in this very trough, mountains are now in the making, and even if this be disputed, we have seen that a great chain of a mountain system is already erected in it.

Ancient geography was different. Long, narrow seas persisted for long periods, and the beds assembled in them enable us to trace the distribution of their channels, at least in part. One of the best known was that followed closely by the Alpine Mountain system from Spain to Burma. It was not the same depth everywhere, but was made up of a number of long basins strung together like a chain of sausages, and there is no good reason to think that the string of them ended exactly at either end where the mountains now come down to the sea. It may have gone on much farther, but though the evidence suggests that they did, there is none to indicate how far they continued. Another system of these super canals traversed North and South America, and it, too, had well-defined basins alternating with shoals which may, at times, have been elevated above sea level. It is suggested that this chain extended south of Tierra del Fuego, following the island arc into Grahamland, and perhaps beyond that. Farther off in time, other geosynclines have been in existence. One followed the line of the Urals, one the course of the Allegheny Mountains, and it seems to have been part of a chain with neighbouring basins extending across the U.S.A. to the west, and one crossed Europe from Spain, via Ireland, to Western France and Czechoslovakia in a curving course across Germany. Another seems to have occurred in the southern tip of Africa, and a counterpart of it appeared in the Argentine. All these canals had complicated histories. Sometimes they moved up and were waterways between continents; sometimes they moved down and the contiguous lands themselves were flooded to such an extent that the geosynclines could only have been detected by a geographically minded fish or reptile.

Some maintain that mountains start to rise centrally from the very floor of a geosynclinal basin, and this may be true in certain instances. However, in some clearly exposed and regionally mapped cases, the first ranges formed close to one of the banks of such a great canal. In the construction of the present chains in South-western Persia the remnants of three sheaves of folds thrown up one after the other on the margin of the old geosyncline play a prominent part (Fig. 2). When a new series of great folds has buckled up on the edge of a narrow sea, the floor of the trough seems to have been pressed down just in front of the new wrinkles. This moat is called a " fore-deep." It is frequently about 40 miles wide, very long, and deeper near land than it is out to sea. Thick deposits are caught in it, and these pile up, while the newly formed mountains are rapidly worn down. There are coarse conglomerates over a very narrow strip

FIG. 2.

DIAGRAM OF THE S.W. PERSIAN MOUNTAIN STRUCTURE.

near the mountain foot, then comes a broader belt of grits, followed by a wide band where sands in narrow lenses interfinger with silts and muds in a very variable sequence. Sometimes there may be several 6-inch sands with only an inch or two of silt between them; sometimes many varying beds of silt and mud with a rare thin, sandy band only once in a 100 feet; and sometimes an almost regular alternation of sand and silt. Among the coarse deposits of near-shore type there are also narrow reefs of limestone. The whole packet was formed quickly, and is called "flysch," whether it was laid down 400 million years ago in the Palæozoic, or only 50 million years ago in the Kainozoic (Tertiary). Farther from land—say, from 40 to 60 miles from the foot of the coastal mountains—the flysch tends to grade into more homogeneous deposits, like silts, muds, or marls, and these may be dark with carbonaceous matter, perhaps oil, or potential oil, or a residue after oil, or only inert carbon, a kind of oil abortion. The flysch is very characteristic, sometimes near to great oilfields, sometimes not immediately connected with them. It is intimately associated with the Polish and Rumanian oil, and some occurs in the Caucasian, Persian, and Dutch East Indian oilfield provinces and features again in the Mexican oil-belt. Flysch constitutes a sedimentary type peculiar to the foot of steep ranges, and seems to be the emergency filling shot down by the weather to make good the hole which accompanies a wrinkling of the earth's crust which has been too vigorously pressed. Upon this "fill" as a foundation the deposits of a more leisurely type are then built up, and they, too, may be thick and likely to produce oil.

We take the view that oil is of sedimentary origin, but does not accumulate in workable quantities as a result of deposition alone. It is disseminated among other sediments. However, as a liquid it is mobile, but some force is required to set it moving before it can collect into the lusty lenses known as fields. Two types of force are available to do this work. The one is gravity, which acts everywhere as the materials settle down; the other is lateral pressure, produced, at least in part, by mountain building. The beds in any column of sediments differ in permeability from horizon to horizon. Some of the sheets are chosen by the fluids as desirable places of residence, some as channels of easy movement, and some of them as layers of no passage. Even if there be no plastic flow of the sediments during folding to act as a kind of hydraulic press when a packet of strata is folded, parts of the packet are lifted up and parts depressed, so that the fluid content has to move to restore its equilibrium, assuming, of course, that the permeable beds are not wholly waterlogged. The combined forces result in the most convenient strata filled up with fluids, and these in turn make gravity adjustments among themselves. This soon gives rise to the conventional pattern of oil and gas in the anticlines and water in the synclines. The conditions favouring this result may be found at any one time over a rather wide strip. Near the core of the mountain things may have been much too hectic if intrusions of eruptive rocks occurred or if strong plastic flow took place accompanied by fracturing. In this zone fluids are not preserved. They are boiled off or squeezed out. Then comes the flank, where things are cooler and quieter. Somewhere in it a strip is reached where the folds are entire without any faulting, consequently they may be suitable structures for

easy fluid movement, but where the folding has been so vigorous that all the beds in the sequence have suffered jointing. In this case the layers which would normally canalize the movement between them, whilst prohibiting passage through them, may have so many gaping fissures across them that they permit disastrous leakage to take place. The zone is next found were folding is adequate and where, under the conditions of cover existing at the time of movement, the impermeable strata remained tight. Similar conditions may occur for a long distance away from the mountain system's axis, and so long as they do obtain, a belt of probable oilfield development continues. Still farther afield, although warping occurs which may be connected with the mountain building, the principal factor inducing accumulation becomes the movement produced as the beds settle down and their particles pack together during consolidation.

The three divisions of country produced during the folding of mountains, then, are :—

(i) the central core with too much heat and disturbance,

(ii) the flank where fields are simple and some of the folds at least not too tight to render all the impermeable beds concerned open-jointed, and

(iii) the outer zone where the suite of folds inaugurated by the pulses of compression has died out.

It is commonplace, though sometimes overlooked, that each case must be considered in the light of local conditions. One impermeable cover rock may be perfectly gas-tight, with curves on its surface the radius of which reaches 1000 feet, as, for instance, in a packet of thin-bedded gypseous marls with interbedded sheets of salt, gypsum, and anhydrite. Another may perform its conserving function satisfactorily only when its curves have radii never falling below 10,000 feet—as, for instance, may be the case in some splintery argillaceous limestones. Unless the impermeable bed is able to achieve plastic flow under the conditions obtaining, it has a critical radius of curvature below which it will joint and leak. In any fold, therefore, there is a limiting factor of flexure determining the capability of that fold to hold oil and gas. Examples of such significant difference of folding are provided by structures on the north-east and south-western sides of the Persian Gulf. The rather strong folding in the Persian oil-fields thoroughly joints the limestone housing the oil, but leaves the Lower Fars saline series which folds easily impermeable. This traps the precious fluids securely, for even if its beds rupture or joint, the cracks seal off at once through plastic flow. On the Arabian side of the Gulf there is no saline series, but, because the folding is very much milder, shales and marly limestones, which are useless for the purpose in Persia, are satisfactory in the rôle of cap-rock in Arabia. It is not impossible that a failure to grasp the implications of radius of curvature may have had some part in determining the course of oil politics in this region.

As a sequence to our partition of the mountain ranges into good, bad, and indifferent oil-belts, we may glance along some of the chains with an eye to the future. Starting in Western Europe, we find the Alpine zone very much disturbed, but with some possibilities in Southern Spain, in the Pyrenees, and in Sardinia. The Rhone Valley, the Swiss Plains, and

the foothill through Southern Germany to Vienna all lie in the interesting belt. The complications and burial of important zones by the sliding down of plastic sheets from off the High Alpine Core have been referred to above. Thus, it would not surprise the contemplative geologist if oil were found in one of the northern Swiss valleys. The Carpathians and the Caucasus have already yielded copiously, but there are unproductive gaps between the present fields. Some of these gaps may be shortened, or even filled in. Across the Caspian, fields are being opened up along the front of the Kopet Dagh and among the foothills in the Duab in Turkestan, and for a long distance along this southern edge of Central Asia, more fields are likely to accrue. On the south side of the Alpine folds the North African province has been tantalizing, but may yet make good. Italy is in the same category. The eastern shores of the Adriatic, where not too broken up by faults, have already given more than a promise and are far from being fully exploited. From Syria eastwards the southern folds have proved their worth not once, but many times, in Iraq, Persia, and Arabia. What happens to them east of the prong of the Oman peninsula is not clear. The Alpine chain does not seem to go through Baluchistan east of Bandar Abbas, and it does not make any convincing feature to the west across the Rub al Khali, so far as the described coastal sections show. Perhaps the range links up with the Carlsbad Ridge off Socotra, and the hiatus may be one akin to that in north-eastern Syria, where country exists in an almost unwrinkled state between the chains of Damascus and Palmyra, on the one hand, and those of Kurdestan and Persia on the other. If the Carlsbad Ridge be indeed a recrudescence of the Alpine type folds of Persia, it turns back upon itself, forming the Murray Ridge, much as the Apennines do when they deflect and swing on into the Dinaric Alps in the Balkans. In India, from Karachi to the Salt Range, on along the foothills of the Himalayas into Assam and then into Burma, the Alpine belt is clear. Here and there oilfields exist. More will be found, and probably some are hidden under the slumped or thrust-sheets along the Himalayan front, displaying a kind of kinship with the Albertan fields of Canada. The group developed further east in the Dutch East Indies is already partly proved.

The American backbone is dotted with fields from Canada to Mexico. Some of them, like those in Alberta, are proving extremely coy, but, given perseverance, they are eventually being won. More have yet to be discovered here, and further finds are particularly likely in Southern Mexico. If we ignore the Antilles because so much of their body is submerged, and proceed to scan the south and east of the Andes, we see that the most obvious prizes in the oil world as yet available are beginning to be collected. The Venezuelan Llanos has its fields, Colombia dangles the luring bait of the Meta River, with its seepages, before the noses of the Oil Fraternity and some one of them will surely be hooked. Peru, ahead of its time, has the audacious field of Aguas Negras, and, like the king with Banco's ghost, " carries in his hand a glass which shows me many more." The rest of the Andian foothills promise well, but their yield is delayed by physical, climatic, and political difficulties. The strip along the Andes from end to end is of high potential value, and exploitation in it is only just begun.

We have seen that mountains have had varied histories and many of them have been folded in several stages. In addition, most of them have experienced phases of vertical movement at a late date. To this we owe much of their present grandeur, because uplift and erosion go on together. In the Alps this movement impresses every tourist who thinks about the sculpture of scenery. The uplift has been well over a mile in amount, and if we go by the caricatures passing for sections of the mountains drawn by some visionaries it may have been much more. In Persia the drained lakes and deep-set gorges point to an uplift of not less than a mile. In the Himalayas the recent elevation is at least as much. In Venezuela, near Caracas, the uplift is more than half a mile, and in Peru not less than two miles in the Central Andes. Large blocks of country have been raised. Some of them remain nearly flat. Some of them have been tilted and some of them warped. The ruined plateaus produced are often bordered by large faults, and the detritus from the uplands sometimes accumulates in thick sheets on the flanking lowlands. The old mountains of 200 million years standing moved up in the past and were ground down, like their younger relatives to-day. The Appalachians, the Urals, ranges in Central Asia, and the Blue Mountains in Eastern Australia have all risen vertically again in rather late time. The result of these movements makes the mountain cores available for inspection in valley sections. The higher parts of the flanks suffer strong wear and tear until their anatomy, too, is freely displayed in gorges and gullies gashing the hills. The outer parts of the original band where there was comfortable folding, however, still lie blanketed with an adequate cover, and they may have had new deposits heaped upon them. In this case their outer folds are covered from view and may be detected only by inference from physical measurements.

On account of these differential vertical movements, samples of the structures still buried and the counterpart of the containers still holding accumulations of oil can often be inspected in the mountains' flanks. Not only are there structures laid bare which simulate those laboriously worked out by making contour plans or peg models from drilling records, but both in the Zagros Ranges and in the Andes the dissected corpses of oilfields can be seen, fields comparable in dimensions with large ones now in exploitation. Their permeable beds lie there, dark with the dregs of their hydrocarbon blood congealed, and their anatomy as stark as if on a dissecting table. No medical man can qualify until he has passed a gruelling course in practical anatomy. Is it not urgent that the oil-man, be he engineer or geologist, should have a sound knowledge of *practical* structure before he proceeds to practise or attempts to prophesy about structure which, because it is deeply buried, must be largely inferred?

We saw that the vertical movements result in fractures which bring lowland areas close to highlands. In these circumstances, oil already trapped and housed in folds may start to leak and flow along some of the fault-planes. This outflowing oil would soon be lost, but a boxed-in sump is well placed to receive and accumulate boulders, sand, and mud at uncommonly high speed. These deposits fulfil the double duty of plugging the leak and absorbing the discharge. In the course of consolidation and the later movements they may be fashioned into comfortable new quarters

for the transferred oil. The adjoining regions in South America of Maracaibo and the Magdalena valley come to mind as type examples, whilst the Pacific coast fields in the U.S.A., as well as in Ecuador and Peru, have features in common with them. These are the only oilfields associated with the western part of the great mountain system of Western America, which differs essentially from the Alpine chain on account of the imposing array of immense granite masses incorporated with it. These are the largest known individual masses of eruptive rock, and they are strung out along the coast from Alaska to Patagonia, and their presence undoubtedly diminishes the prospects of the terrain as an oil one.

This review of mountains, their distribution, their origin, their constitution, and their destruction has shown us that they play a great part in the oil game. They stand in the belts where the greatest thickness of sediments has assembled, and the more sediment, the more the chance of oil. They are the welts where many gradations of folding occur, and hence they provide a great choice of structures, in some of which liquid oil can and does gather. They are the rain-makers, and, as such, they keep the pot of sedimentation boiling, and so have maintained conditions in which oil has been able to form from time to time, and can still do so. They form barriers in the oceans, and influence the course of deposition on the one hand, and the type of bottom conditions on the other. Some are suitable and some inimical to oil formation. They are singularly susceptible to uplift, which may ruin some fields whilst bringing others within the reach of the drill. With uplift may go collapse, after which oil is liable to move along fractures, though it may be caught again by hasty piling up of beds derived from the highlands around. Finally, they provide an ideal school for the budding oil-man. There he can see the rock column, the reservoir rock, the cover rock, and perhaps the mother rock itself. There he can see in three dimensions the actual structures, and the type and progress of the joints which cross them.

We live in an age when education is a popular subject for discussion and at a time when there has been a break in the continuity of training and recruitment of those who must carry on the technical side of oil production. Is it not an appropriate time to ginger up the artificial and theoretical curriculum with more than a laboratory to elaborate the lecturers' themes? Is it not a time to think of a course when the students shall work for a time in one of those favoured lands where oilfields exist and, more important still, where they have existed, but are now dissected, and where the mountain-sides hold their ruined bodies naked and unashamed? Men with such a training would be then well equipped for the task awaiting them in the near future, in the deserts and jungles of India, on the Canadian prairies, on the plains and in the swamps of Mexico, around the Atlas Mountains in Africa, and in that Eldorado which is waiting to be opened up in the forests at the head of the Orinoco, the Amazon, and the Paranà Rivers from Venezuela to the Argentine.

THE INSTITUTE OF PETROLEUM.

A MEETING of the Institute was held at Manson House, 26, Portland Place, London, W.1, on Tuesday, May 9th, 1944. The President, Professor F. H. Garner, occupied the Chair.

The following paper was presented by Dr. J. V. Harrison :—

"Mountains and Oil." [See pp. 243–253.]

DISCUSSION.

THE PRESIDENT, opening the discussion, said that Dr. Harrison had given a very stimulating talk, and that he could understand now why the series of lectures he gave to the students at Birmingham last session had been so much appreciated.

The reference to the plastic flow of the rock materials, when the tops of mountains slide down into the valleys, was of great interest. In the part that was sheared off, was there an actual flow ?

DR. HARRISON said that he had seen a sheet of limestone 1000 feet thick which had peeled off a mountain side and folded over on itself, producing a structure called a flap. The flap was 8 miles long and 3 miles wide, and had taken place without a break along the hinge line. This suggested plastic flow.

DR. G. M. LEES said that he found it very difficult to comment on Dr. Harrison's very interesting address, for he had taken them around the world such a number of times and had touched on so many aspects of his subject. They had made many journeys together; he was, of course, the great mountain enthusiast *par excellence*, and it was a real delight to travel with him through the mountain country which he knew so well.

In the course of his address Dr. Harrison had given certain interpretations of some very complex mountain structures, and had mentioned the phenomenon of gravity sliding. Quite frankly, he admitted at first he had refused to believe it; but after having been frog-marched around some of his mountain examples he had had no option but to believe it. He joined in the author's enthusiasm for the importance of gravity sliding in special cases, but he feared that he could not go all the way with him in extending the theory quite so widely as he had done. However, he had lagged behind him even in the initial conception of gravity sliding, and it might be that there was delayed action in his understanding !

In Dr. Harrison's survey of the world his emphasis had been all the time on mountains. It was perhaps unfair to criticize his address on the ground that it lacked reference to the great oilfields of the plains, as he had set out to deal with mountain zones only, and had indicated where some of the oilfields of the future might be found in those zones. But there were great areas of plains, in the intermediate zones between the mountains of the old shields. For example, on one of his maps there was a most significant extent of blank areas, the very extensive plains of European and Asiatic Russia. But they lay far out from the mountain areas, and were excluded from his survey.

However, he agreed with Dr. Harrison on the great importance of the mountain areas and the degree to which they had yielded oil, as well as the possibilities for the future. The great range of the Andes and the belt lying east of the Andes was probably one of the least known parts of the world so far as its oil-bearing possibilities were concerned. He even referred to the great sub-ocean ranges, up and down the Atlantic and backwards and forwards into the Pacific. Whilst one agreed that there might be many buried oilfields there, he was afraid that we should have to wait another 20 million years or so until they in their turn were uplifted; it would then be for our remote descendants to deal with the anticlines.

In the high mountain countries there had been many oilfields which had been bled to death, so that one could see only their skeletons. He agreed entirely with Dr. Harrison that it should be part of the experience of every oil geologist to visit the mountain countries and to see the skeletons of the oilfields of the past. He supported fully his suggestion that students be given every opportunity to enlarge their experience of mountain geology.

He would like, in conclusion, to endorse the President's remarks that it had been a great pleasure to hear Dr. Harrison's address, and to see his sections and diagrams and particularly his mountain photographs.

Dr. Harrison thanked Dr. Lees for his remarks, but did not think they called for extended comment. He was aware that he had not discussed the potentialities of the intermediate areas between the mountain ranges, as they lay outside his terms of reference. So far as the interpretation of the Alpine structures was concerned, he was by no means leading the way, but was humbly trying to follow Dr. Harold Jeffreys. He had tried to draw a diagram which was more specific than the generalized ones Dr. Jeffreys had published in 1931. But he did think that Dr. Jeffreys and others were on the right scent when they brought to our notice the possibility that ridges on the earth's surface had somehow or other been humped up higher than they could bear, and that in order to acquire a position of repose there had been a sliding down of material. That was a subject for engineers as well as geologists to pursue. The strength of materials is such that they will stand only limited strain, and rocks in thin sheets will not stand indefinite pushing about. In his opinion a thin packet of rock might behave rather like a fluid, and slip and sag downhill. At all events, packets of rocks have assumed attitudes which recall those observed in slabs of wax which have suffered slow distortion by flowing.

Mr. E. Thornton said that the fascinating survey of world geography and geology seemed definitely to establish sound relation between mountains and the position of oil, and unless we assumed that all oil had migrated, some relation between conditions leading to the formation of oil and its location with regard to mountains seemed to be established. Had any similar theory been formed or any such correlation been established between the position of other products of sedimentation and decay and earth rock structure, *e.g.*, could we predict where to look for shales or coal by reference to mountains?

Dr. Harrison replied that it seemed to him that oil shale, being a deposit which is fine in grain, was likely to occur at a considerable distance from a mountain range. It was a type of deposit which he would expect to find more abundantly in the intermediate areas of the land surface of the earth than in the mountain country, because whilst this was the region in which the deposits were the thickest, it was also the region in which the deposits tended to be coarse. He could think of no considerable oil shale deposit which occurred close to mountains, but he could think of many which occurred at some distance from mountains, in the more peaceful regions between the mountains and the bosses of the ancient shields.

On the motion of the President, a hearty vote of thanks was accorded Dr. Harrison for his address and illustrations.

SPECTRAL METHODS AND THEIR APPLICATION IN THE PETROLEUM INDUSTRY.

By W. H. Naylor, Ph.D.

Many of the modern advancements in the physical sciences have had their inception in spectral investigations. The knowledge of the light-emitting and absorbing properties of various materials has provided a means whereby both qualitative and quantitative determinations may be made. Among the early workers in the field were Bunsen and Kirchhoff, who in 1859 utilized flame spectra for analytical purposes. Since that time there has been extensive development in the use of emission spectra. The metallurgical industries, in particular, rely almost exclusively upon arc and spark spectrographic analysis for control. All branches of chemical industry use spectral methods, both for analysis and in investigative work. It is to be expected that as the petroleum industry turns more and more from a producer of raw materials to a chemical industry, it also will increasingly utilize methods of analysis.

X-Rays

Since the discovery forty-nine years ago by Röntgen of a type of radiation which he called X-rays, the development and utilization of these rays have become a full-fledged science. X-rays can find application in almost all industries and in many other fields. Many industries now use X-ray measurements for control and inspection, and it is probable that others will soon begin to realize the potentialities of their use. Many present-day industrial uses are given in the symposium presented in the May and July 1941 issues of the *Journal of Scientific Instruments*.[1] Equipment may be obtained which ranges in size from large installations for cancer and sub-atomic research to small portable instruments used to locate pipes and wiring in walls.

X-rays are produced when an electron fills a vacant space in an inner electronic shell of an atom. Thus in order to produce X-rays at will, one must have means at hand which will knock electrons out of various atomic electronic shells; the primary method generally used is a stream of electrons, accelerated in an electric field, striking a target consisting of a high-melting metal. The moving electrons or cathode rays remove electrons from various shells, even the innermost shell, if they are accelerated by sufficient potential. The electronic rearrangement which follows produces X-rays whose wave-length depends on the target element and on the energy difference between the initial and final position of the electron that shifted towards the atomic nucleus. The highest energy differential—*i.e.*, going from the outer shell to the innermost shell—produces X-rays of the shortest wave-lengths and highest frequencies. Secondary X-rays may be produced by irradiating a substance with X-rays, whereupon the substance radiates X-rays of longer wave-length. Each chemical element, when suitably

activated, will emit X-rays of characteristic wave-length; this provides a valuable method of qualitative analysis.

There are two general fields of application of X-rays in industry: first, the macroscopic examination of materials to reveal the inner structure, and second, the diffraction of X-rays to reveal the atomic arrangement in materials. In the first field, photographing or fluoroscoping the casting or forging under illumination of X-rays will show internal faults, if such exist. The only method of testing a weld without destroying it is to use X-rays; furthermore, the strength of a weld may be well predicted from an X-ray photograph.

The use is not limited to metallic substances. The application to the petroleum industry is apparent, at least in construction work in inspection of welds, condition of refractories, etc. It is probable that it would prove useful in routine equipment inspection to predict where failure of tubes or plates is imminent, but before such failure occurs. Moving pictures by X-ray have been used for research in biological fields within recent years. Stroboscopic and ordinary moving pictures by X-ray would be useful in motor research.

The diffraction of X-rays by crystals was the first application of X-ray analysis. In 1912 von Laue and co-workers [2] developed and tested a theory involving interference of X-rays. A year later, W. H. and W. L. Bragg [3] found that crystals might be used as interference gratings for X-rays. Each crystalline solid gives a characteristic diffraction pattern, and may be identified thereby. The arrangement of the atoms in the crystals may also be deduced. Present applications include identification of substances on a purely empirical basis from the diffraction pattern, structure of alloys, allotropic changes in refractories, measurement of stresses in metals by measuring changes in crystal-lattice dimensions,[4] identification of intermediate products in chemical processes, and following changes in catalyst structure during operation. In the last example we find a particularly useful field of investigation in the petroleum chemical industry. Catalytic processes in this industry are becoming very prevalent, but our knowledge of the action of catalysts is still largely empirical. X-ray study in this field under actual operating conditions may give us catalysts of greater activity and longer life. Since the original material incorporated in a catalyst is often a mixture of oxides, it may be well to study the catalyst during and after operation, for the existence of some oxides as such is unlikely at the temperatures and conditions used. The gradual loss of activity may be due to a progressive reaction within the catalyst itself.

Ultra-violet and Visible

Those portions of the spectrum which are called the ultra-violet and the visible regions are considered to be the result of shifting of electrons to various energy levels in the valence or outer electron shell. The electrons are moved to higher energy levels away from their normal positions by absorption of energy from some source, and then, on returning to the normal position in certain fixed jumps, various specific wave-lengths are emitted. These wave-lengths are characteristic of the atom emitting the light although a particular wave-length of high energy may not appear if the

activation energy is insufficient. Let us first consider the application of emission spectra in the visible and ultra-violet.

There are three general methods of producing emission spectra. The material under test is introduced into a flame, or an arc, or, third, into an electric spark. These three methods increase in activation energy in the order named. Flame spectra are generally used for qualitative identification of the alkali metals, although Lundegardh [5] has obtained satisfactory determinations for thirty-two elements using an acetylene flame. The electric arc is at present the most commonly used excitation method for spectrographic determinations. The spark source is used in cases where the sample is volatilized too rapidly by the arc or where activation energy is desirable. The arc and spark light sources may be observed visually after passing through a prism or grating spectrometer, but the more generally used equipment is a spectrograph, which gives a permanent record of a sample on a photographic plate. The actual measurement for quantitative determinations is then in terms of density on the plate of a characteristic line or lines. This is very widely used for qualitative and quantitative analysis of metals, and there is a voluminous literature in this field. By using a high-frequency, low-voltage spark under reduced pressure, most of the non-metals may also be detected.[6]

Emission spectra may be used in the petroleum industry in engine-wear studies, since iron may be detected down to 1 part in a million. Inorganic impurities in crude oil or its various products may be determined. Any metallic equipment, as well as clays, sludges, and catalysts, may be analysed by this means. Spectrographic analysis is of particular importance in the case of catalysts, since the presence of extremely small quantities of impurities may markedly change its efficiency. Emission spectra are used by some oil companies for analysis of cores, soil, and water in oil-fields. It is useful in correlating geological strata, and may have value in prospecting.

Absorption Spectra in the Ultra-violet and Visible

Some chemical compounds possess electronic configurations such that they absorb light in the ultra-violet or visible regions. The aromatic hydrocarbons, as well as many of their derivatives, have characteristic absorption bands in the ultra-violet. Fig. 1 gives the well-known absorption spectrum of benzene. The fact that the paraffins and naphthenes (*cyclo*alkanes) do not absorb in the ultra-violet makes identification and determination of the aromatics possible.

R. N. Jones [7] has recently given an excellent review of the field of absorption of ultra-violet light by aromatic hydrocarbons. The olefins [8, 9] and acetylenes absorb in what is called the far or vacuum ultra-violet. Experimental difficulties in the exact measurement of light intensities in this region limit this field at present to qualitative identifications, but it is to be confidently expected that photoelectric and electronic methods rather than photographic will soon overcome this limitation.

Compounds which absorb in the visible give evidence to the eye that they do so through their colour. That is, a solution of a red dye appears red because it transmits red light and largely absorbs other wave-lengths. The colours of various materials has given rise to innumerable colorimetric

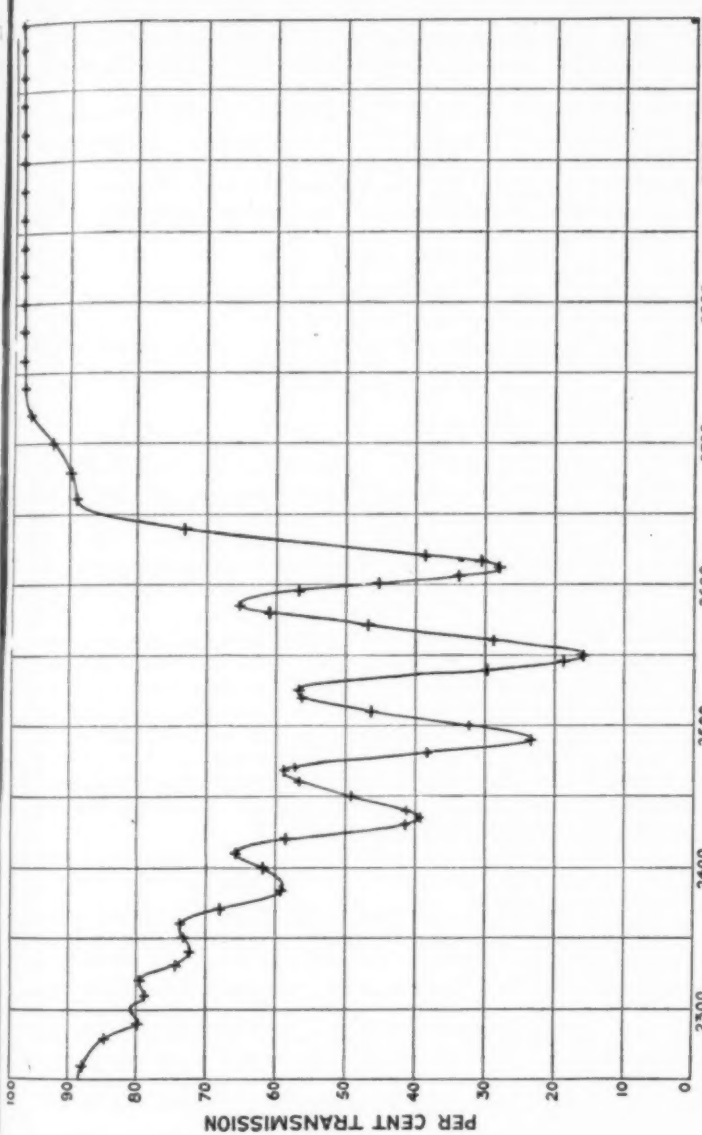


Fig. 1.

BENZENE 0·0045 MOLS./LITRE IN *iso*-OCTANE.

methods which are in use in all branches of science and industry. The method of absorption spectrophotometry is applicable, and presents distinct advantages in many coloured systems. This method involves measurement of light transmitted or reflected at a particular wave-length, and the wave-length may be varied to any position to give a series of measurements throughout a spectral range. The absorption spectrum obtained by such a series of measurements may be used for qualitative identification of a substance. At a particular absorption peak, the values of the original and transmitted intensities of light may be used as a basis for quantitative determination. The law of Lambert and Beer gives the relationship of the quantities involved:

$$I = I_0(10^{-kct})$$

where I = intensity of transmitted light; I_0 = original intensity; c = concentraton; and t = thickness of absorbing layer.

The law may be expressed in another way in terms of the extinction E:

$$E = kct = \log \frac{I_0}{I}.$$

It may be seen that there is a linear relationship between E and the concentration. A calibration curve may be established by measuring E for various known concentrations, and if it is found that the system deviates from the Lambert–Beer law, a smooth curve drawn through the experimental points will serve as a working curve giving graphical values for concentration on unknown samples. Fig. 2 is a calibration curve for benzene, using the absorption peak at 2548 Å. Some instruments will automatically trace out an absorption spectrum similar to Fig. 1. The non-automatic photoelectric spectrophotometers now available give ease and rapidity of operation. The colour of a material is more precisely characterized by its absorption spectrum than by any other means. Several hundred pure dyes may be identified from their absorption spectrum, and in many cases mixtures may be analysed.[10] Metals in very small concentration may be determined quantitatively, using various organic reagents to produce a colour. Iron has been determined with *ortho*-phenanthroline,[11] 2 : 2-bipyridine,[12] mercaptoacetic acid,[13] and others. These methods are quite adaptable to wear and corrosion studies.

Infra-red Absorption Spectra

With but a few exceptions, all chemical compounds have characteristic absorption bands in the infra-red. These bands correspond to interatomic vibrations and molecular rotation. The region of the infra-red from 1 to 23μ comprises the vibrational spectrum, and it is the region generally studied, since the far infra-red, corresponding to the molecular rotation energies, extending up to 200μ, presents great experimental difficulties. The rotation energies superimposed upon the interatomic vibrations may produce fine structure on either side of the main vibrational band. Under low resolution this merely broadens the absorption band. Except for enantiomorphous stereoisomers, different molecules have different infra-red absorption spectra. Compounds in an homologous series usually have certain bands in common, although they differ in intensity. *Cis* and

trans,[14] as well as other types of isomerism, give different spectra. Various functional groups, as O—H, C=O, C=C, etc., have characteristic frequencies.[15] The C—H group has a different frequency in aromatic compounds

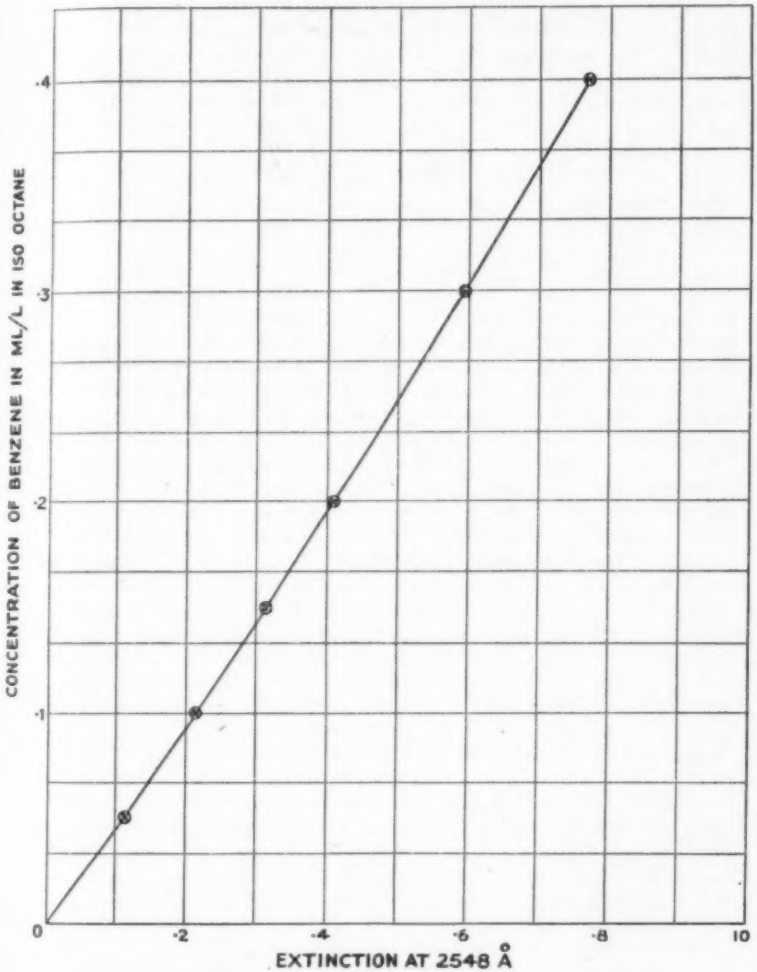


FIG. 2.

CALIBRATION FOR BENZENE.

than it has in aliphatic compounds; this difference may be made the basis for a determination of aliphatic and aromatic compounds in a mixture.[16] The characteristic frequencies of the various groups is valuable in deter-

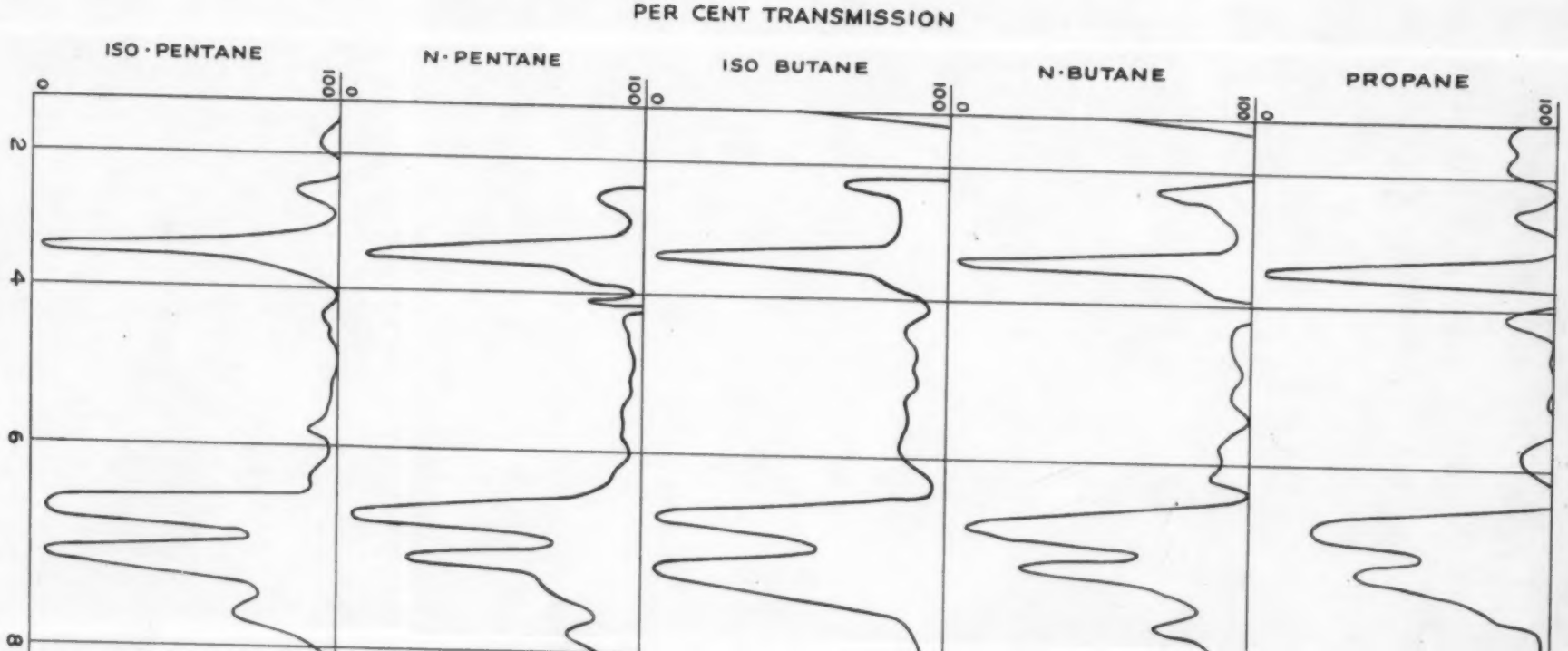
mining molecular structure or the presence in a molecule of a particular group. For example, Gordy and Williams [17] were able to distinguish between normal and *iso*cyanides. Isomerization, association, chelation, polymerization, and keto-enol isomerization may likewise be detected. The configuration of atoms in *cyclo*hexane has been elucidated by Rasmussen as corresponding to the chair form as distinguished from the cradle form.[18] The calculation of bond angles between atoms, moments of inertia, and thermodynamic data—free energy and entropy—is possible in some cases using infra-red spectroscopic data.[19, 20] Rose and others,[21, 22, 23] have shown that the molal absorption coefficient K of paraffins dissolved in carbon tetrachloride is a linear function of the number n_1 of methyl groups, the number n_2 of methylene groups, and the number n_3 of tertiary-CH groups.

$$K = \alpha n_1 + \beta n_2 + \gamma n_3$$

where α, β, and γ are constants for all paraffins but have different values for different wave-lengths. This makes it possible to calculate the structure of an unknown paraffin from its infra-red absorption spectrum after first determining the values of α, β, and γ for several wave-lengths on a known hydrocarbon. Rose applied this method to determine the structure of a nonane, and his results were later verified by synthesis. This method may also be used for aromatic-CH groups and for aromatics with aliphatic side-chains.

Infra-red absorption spectra have been used in problems of molecular structure ever since Lord Rayleigh showed in 1892 that a vibrating and rotating diatomic molecule which possessed an electric moment should emit and absorb radiation at or near the frequencies of vibration and rotation. The investigations of Coblentz [24] in 1905 on several hundred compounds did much to correlate the existing knowledge on infra-red spectra. The use of the absorption spectra for analysis has come in recent years. In 1932, Lecomte and Lambert [25] began to analyse hydrocarbon mixtures. Wright [26] and his co-workers have applied infra-red spectra to a wide variety of industrial analytical problems. In one application they have set up an instrument for control of distillation of hydrocarbon gases which continuously records and analyses the absorption of the gas flowing through a cell. Fig. 3 gives the absorption spectra of several hydrocarbon gases. The analyses of several binary mixtures have been described in the literature: the *cyclo*pentane cut with 2 : 2-dimethylbutane as the principal impurity,[27] *iso*butane and normal butane with small amounts of propane and *iso*pentane as impurities,[28] *cyclo*hexane in toluene,[16] hexane in carbon tetrachloride,[16] and others. In the case of hexane in carbon tetrachloride, amounts as small as 1 part in a million of the hexane or other paraffin may be detected; this may be used as a basis for the determination of higher aliphatic compounds in earth samples. The use of the characteristic frequency bands gives a method for determination of the total of several members of an homologous series, as for example the olefins or acetylenes. It should be emphasized that these methods are very rapid as compared to conventional methods.

The analysis of multi-component mixtures from infra-red data is a field which has not yet received much attention in the literature. It is never-


PER CENT TRANSMISSION
ISO · PENTANE
N · PENTANE
ISO BUTANE
N · BUTANE
PROPANE
100
0
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INFRA-RED

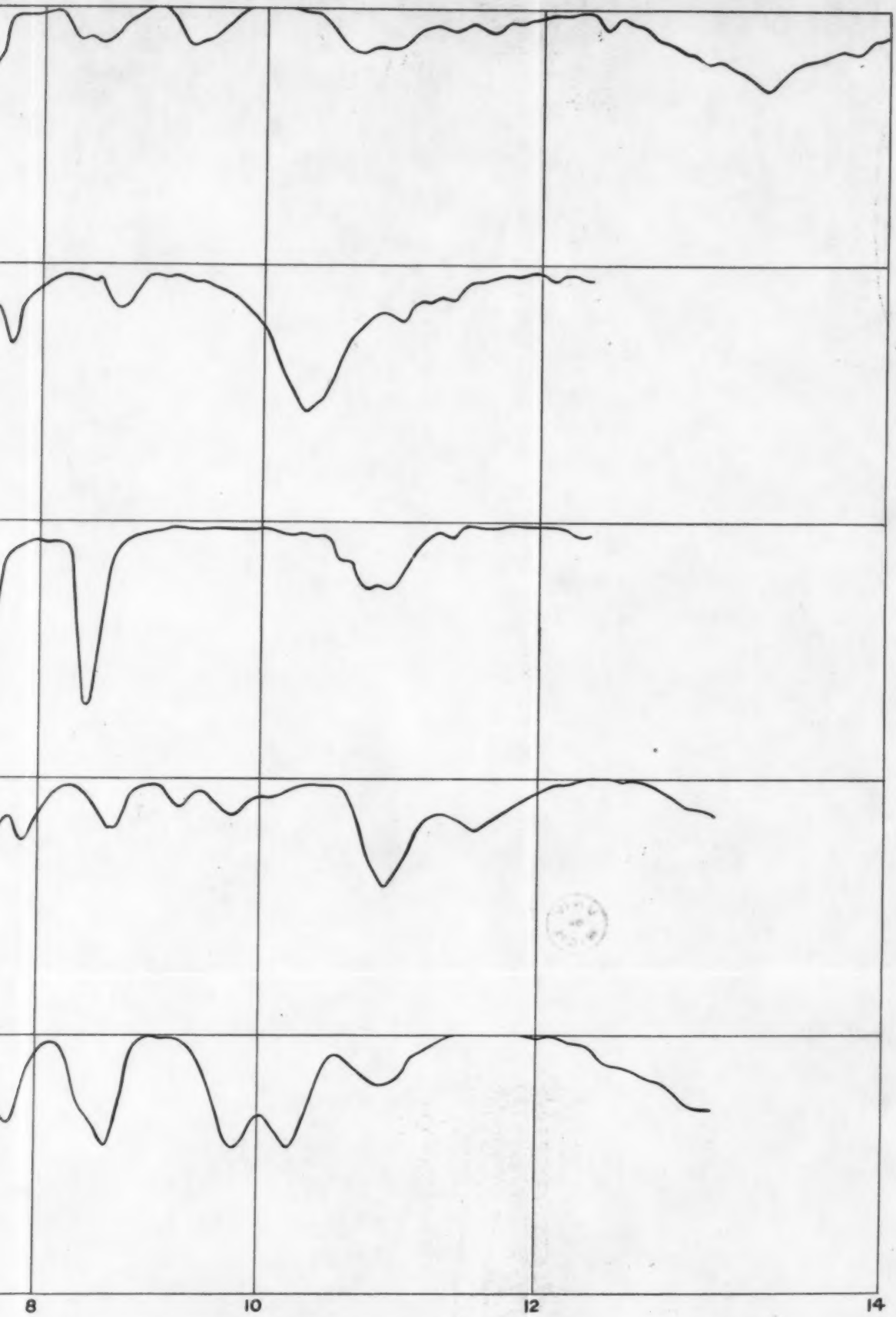

FIG. 3.

A-RED ABSORPTION SPECTRA OF SOME HYDROCARBON GASES.

[To face p. 262.

theless being actively investigated in numerous laboratories, and in some cases well-defined methods are in use. The possibility of analysis of any mixture will depend on the number of components and the dissimilarity of their spectra. If, in a particular mixture, the absorption bands overlap too much, the use of a different concentration, or a lower temperature, or an instrument of higher dispersion may solve the difficulty. The data from another portion of the spectrum may help to make analytical interpretations. A description of the method of calculation for a multi-component mixture is given by Brattain.[29]

Many of the wide-range cuts from the distillation of petroleum are so complex, particularly in the higher-boiling ranges, that an analysis for components may be impossible by any spectral or by any other means. It is, however, possible to use the infra-red absorption on a purely empirical basis to control a process. When the influence of the variables in a process on the absorption, and the absorption of the desired product, are known, the measurement of this throughout the process may be used for control; indeed, for automatic control. Infra-red emission spectra may perhaps be brought into use here. Emission radiation in the infra-red appears to have received little attention to date.

Raman Spectra

In 1928, Raman discovered that when various substances, usually liquid, are illuminated by a monochromatic radiation in the visible or ultra-violet, the molecules will for the most part transmit the light unabsorbed. However, some of the light is absorbed by the molecules and then emitted at a frequency different from the original. The scattered light of changed frequency is usually on the long wave-length side of the original, although some light of higher energy per photon is obtained. The difference of frequency $\pm\Delta\nu$ multiplied by Planck's constant gives an energy corresponding to infra-red radiation. Apparently, then, the Raman spectra is in effect a measurement of an infra-red absorption spectrum, although the measurements are made with visible light. The small amount of scattered light of changed wave-length makes observations difficult, and a spectrometer of high dispersion is needed to separate the various Raman lines. The low light intensity of the Raman spectra has necessitated long-exposure photographic measurement; however, Rank [30] has succeeded in using a photoelectric technique with sensitivity which compares favourably with the photographic method. Work in the field of Raman spectra has the distinct advantage of being in the visible range, where the equipment is not so delicate and where there is a much greater backlog of experience and instrument development.

A number of workers have used Raman spectra for analytical purposes. Shorygin [31] has had considerable success in analysing gasoline components. Grosse and co-workers [32] have used Raman spectra for identification and semi-quantitative analysis of paraffins up to C_8. The alkylacetylenes and other hydrocarbons have been investigated by Cleveland.[33] Rank [34] has written on the qualitative and quantitative analysis of hydrocarbons.

Mass Spectroscopy

This paper would not be complete without a consideration of the mass spectrograph, even though it does not deal with a portion of the electromagnetic spectrum. Thompson [35] did the early work on the action of positive ions in electric and magnetic fields. Aston [36] was the first to build an instrument to analyse positive ions using the principles of the mass spectrograph as we know it to-day. He, by the use of an electric and a magnetic field, was able to spread a mixture of positive ions into a spectrum where all ions of the same ratio of charge to mass were brought to focus on a line on a photographic plate. With this instrument he measured the masses of many isotopes of the elements with an accuracy of 1 part in 10,000. The mass spectrometer can be constructed and operated in such a way as to measure the relative abundance of ions of a given mass. If a hydrocarbon mixture or other sample which is fully vaporized at 30–40 microns pressure be introduced in the ionizing chamber of a mass spectrometer and bombarded with electrons, some of the molecules will be ionized by the knocking out of one or more electrons. Other molecules will be broken up into ionized fragments. The particular fragments formed and their relative numbers are dependent on the original substance, and various hydrocarbons as well as other compounds have characteristic mass spectra. Interpretation of the spectra is complicated by the fact that a particular fragment is not specific for a compound, but may be formed from several compounds. It is only the relative amounts of several fragments which identify a compound. Hoover and Washburn [37] have had considerable success in interpreting the spectra and in using the mass spectrometer for qualitative and quantitative analysis. Instruments are available and are in use in the petroleum industry [38] as well as in other industries.[39]

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PRELIMINARY LIST OF DEFINITIONS.

BY STANDARDIZATION SUB-COMMITTEE NO. 11—NOMENCLATURE.

Preface.

At a meeting of the Standardization Committee held on 1st October, 1943, it was decided to appoint a sub-committee whose task would be to prepare a glossary of common terms used in the Petroleum Industry. The terms of reference of the Sub-Committee were that the definitions should be couched in as simple language as possible, in order that the non-technical reader could consult the Glossary and derive, it is hoped, a real benefit from it.

So far it has only been possible to deal with terms covering petroleum products which, in the main, are widely distributed. In some instances terms used in well-known tests associated with these products have also been defined. It is hoped, later, to extend the work of the Sub-Committee to embrace refinery nomenclature and terms used in the search for and recovery of oil.

The definitions and descriptions of terms used in the Petroleum Industry which appear in this list represent the usual meanings ascribed to such terms inside the industry. It should be appreciated that the Institute of Petroleum does not consider itself, as a body, responsible for any legal interpretations which might be placed upon these definitions.

B.S. & W. "Bottom settlings and water," comprises the solids and aqueous solutions which may be present in an oil, and which are separable therefrom by means of gravity or the centrifuge.

Butane. A hydrocarbon gas used as a constituent of gasoline in order to confer improved volatility and anti-knock value. It is used also for heating purposes and as a starting material for certain synthetic processes. It can be stored under pressure as a liquid at atmospheric temperatures. By reason of its chemical composition it is classed as a C_4 hydrocarbon.

Carbon Black. A substantially pure form of finely divided carbon usually produced from gaseous hydrocarbons by controlled combustion with restricted air supply. It is used as a filler in the rubber industry, being specially valuable by virtue of the improved wearing quality which it imparts to tyre rubbers. Smaller quantities are used as pigment in printing inks and paints.

DERV Fuel. A term applied in the United Kingdom to types of gas oil suitable for use as a fuel for high-speed compression ignition engines. The term is an abbreviation of "*D*iesel *E*ngine *R*oad *V*ehicle."

Detergent Oil. A lubricating oil possessing special sludge-dispersing properties and used in some internal-combustion engines. These properties are usually conferred on the oil by the incorporation of special additives. A detergent oil has the ability to hold sludge particles in suspension as well as to promote engine cleanliness.

Diesel Fuel. A general term covering oils used as fuel in diesel and other compression ignition engines.

This term usually applies to fuels suitable for those engines of the industrial and marine type which have a low or medium rotational speed, and which are not so critical of fuel quality as are high-speed engines. Fuels for the latter need special descriptions—*e.g.*, High-Speed Diesel Fuel, Automotive Gas Oil, or DERV Fuel (*q.v.*).

Distillate. A product obtained by condensing the vapours evolved from boiling petroleum and collecting the condensate in a receiver which is separate from the boiling vessel.

Distillation Range. A single pure substance has one definite boiling point at a given pressure. A mixture of substances will, however, exhibit a range of temperatures over which boiling or distillation commences, proceeds, and finishes. This range of temperature, usually determined at atmospheric pressure by means of standard apparatus, is termed the distillation or boiling range.

Fuel Oil. A general term applied to an oil used for the production of power or heat. In a more restricted sense it is applied to any petroleum product that is burnt under boilers or in industrial furnaces. These oils are normally residues, but blends of distillates and residues are also used as fuel oil. The wider term " Liquid Fuel " is sometimes used, but the term " Fuel Oil " is preferred.

Gas Oil. A petroleum distillate having a viscosity and distillation range intermediate between those of kerosine and light lubricating oil. Its main uses are in the manufacture of gas for enriching (" carburetting ") water gas, as a wash oil in the extraction of benzol from coal gas, and as a burner fuel in certain heating installations. Suitable gas oils are also used as fuels for high-speed diesel engines. (See DERV Fuel.)

Gasoline. A refined petroleum distillate, normally boiling within the limits of 30–220° C., which, by its composition, is suitable for use as a fuel in spark ignition internal-combustion engines. Alternative terms still in general use are petrol, motor spirit, and benzine. Motor Spirit is legally defined in the U.K. in the following publications:

Finance (1909–10) Act, Section 84(7) and 84(8); S.R. & O. 1942, No. 2400, Section 68(*a*).

H.D. Oil. The letters H.D. denote Heavy Duty, and have reference to the fact that these lubricating oils were originally developed for use in certain types of high-speed diesel engines and spark ignition engines subject to high piston and crankcase temperatures. H.D. oils combine the properties of detergency, resistance to oxidation, and relative freedom from corrosive action on alloy type bearings. Normally H.D. oils contain special additives which confer those properties.

C_3 Hydrocarbons. Any of the hydrocarbons of which the molecule contains three carbon atoms.

C_4 Hydrocarbons. Any of the hydrocarbons of which the molecule contains four carbon atoms.

Inhibitor. A substance the presence of which in small amounts in a petroleum product prevents or retards undesirable changes taking place in the quality of the product, or in the condition of the equipment in which the product is used. In general, the essential function of inhibi-

tors is to prevent or retard oxidation. Examples of uses include the delaying of gum formation in stored gasolines, and of colour change in lubricating oils; the prevention of corrosion is also included—*e.g.*, rust prevention by inhibitors in turbine oils.

Kerosine. A refined petroleum distillate intermediate in volatility between gasoline and gas oil. Its distillation range generally falls within the limits of 150° C. and 300° C. Its main uses are as an illuminant, for heating purposes, and as a fuel for certain types of internal-combustion engines. In the U.K. it is often incorrectly termed "paraffin" or "paraffin oil"; the spelling "kerosene" is now officially obsolete. (See "Power Kerosine and Vaporizing Oil.")

For legal definition see S.R & O. 1942, No. 2400, Section 59.

Light Distillate. A term lacking precise meaning, but commonly applied to distillates the final boiling point of which does not exceed 300° C.

Liquefied Gas. Light hydrocarbon material, gaseous at atmospheric temperature and pressure, held in the liquid state by pressure to facilitate storage, transport, and handling. Commercial liquefied gas consists essentially of either propane or butane.

Lubricating Grease. A semi-solid lubricant consisting essentially of a stabilized mixture of mineral oil and soap. The properties of the material depend on the type of soap employed (lime soda or other base) and the viscosity and other properties of the constituent mineral oil.

Lubricating Oil. Any oil which is employed for lubricating purposes. It may consist of either petroleum or fatty oils, or these two main type in admixture, either with or without additives.

Motor Oil. A refined lubricating oil suitable for use as a lubricant in internal-combustion engines. May be a distillate oil or a blend of distillate oil with a bright stock (*q.v.*).

Naphtha. This term is rarely used to describe petroleum fractions in the U.K., but under the designation petroleum naphtha in the U.S.A., and coal-tar naphtha in the U.K., the term implies a distillate material which boils in the gasoline range.

Naphthenates. The alkali and metal salts of naphthenic acids. Their uses include service as paint driers and as wood and textile preservatives.

Naphthenic Acids. Organic acids found in crude oils from certain sources. They have a characteristic unpleasant odour. Their main use is for the preparation of naphthenates (*q.v.*).

Natural Gas. Gas found in certain localities issuing from the earth under pressure and often produced in association with crude petroleum (*q.v.*), when it acts as an important factor in the recovery of the latter. Natural gas is usually classified as "wet" or "dry," depending on whether the proportions of gasoline constituents which it contains are large or small.

Natural gas is also referred to as "Casinghead Gas."

Natural Gasoline. A low-boiling liquid petroleum product extracted from natural gas. In its "wild" or unstabilized condition it contains fairly high proportions of propane and butanes. The propane and part of the butanes are removed by certain processes, yielding a stabilized gasoline suitable for blending with other gasoline.

Natural Gasoline is sometimes referred to as "Casinghead Gasoline."

Petroleum. A material occurring naturally in the earth, and consisting essentially of hydrocarbons, solid, liquid, and gaseous.

For legal definition see Petroleum (Consolidated) Act 1928, Section 23.

Petroleum Coke. Solid matter formed as a by-product of thermal cracking (*q.v.*) of petroleum. It consists mainly of carbon, and has an ash content very much smaller than that of coal cokes. Certain grades are suitable as raw material for the manufacture of electrodes, but its main use is as boiler fuel at the producing refineries.

Petroleum Ether. A special boiling-point spirit (*q.v.*) of high volatility and narrow distillation range—*e.g.* 40–60° C. or 60–80° C., used in the extraction of edible oils, etc., and for laboratory analytical work.

Propane. A hydrocarbon gas, useful for heating and metal cutting and flame welding purposes. It can be stored under pressure as a liquid at atmospheric temperatures, but is more volatile than butane, and high-pressures are required to keep it in liquid form. By reason of its chemical composition it is classed as a C_3 hydrocarbon (*q.v.*).

Residue (*Residuum*). The material remaining as unevaporated liquid or solid from a process involving distillation or cracking.

Sludge. Acid Sludge. Material of high specific gravity formed during the chemical refining treatment of oils by sulphuric acid, and usually separable by settling or centrifuging. Also known as Acid Tar.

Engine Sludge. The insoluble degradation product of lubricating oils and/or fuels, formed during their use in internal-combustion engines and deposited from the oil on to engine parts outside the combustion space. Water may or may not be present in such material.

Tank Sludge. Material which collects at the bottom of storage tanks containing crude oils, residues, or other petroleum products. Such sludge usually contains water. (See B.S. & W.)

Straight Run. Produced by distillation without appreciable cracking or alteration of the structure of the constituent hydrocarbons.

Topped Crude. Crude oil from which some of the lighter constituents have been removed by distillation.

Viscosity. That property of a liquid which is a measure of its internal resistance to motion, and which is manifested by its resistance to flow. The viscosity of a liquid changes with temperature decreasing as the temperature is increased.

Volatility. The degree to which a given substance or mixture of substances is volatile—*i.e.*, capable of vaporization. Applied to gasoline, for example, the lower the temperature at which a given amount of the material may be distilled, the greater its volatility.

White Oils. A term applied to oils substantially colourless and without bloom made from light lubricating oils by a drastic process of refining. They have various uses, such as for medicinal purposes and in the manufacture of toilet preparations.

White Products. A term applied to the more volatile petroleum products, such as gasoline, white spirit, kerosine (*q.v.*). It is not to be confused with the term "White Oils."

White Spirit. A refined distillate intermediate in distillation range between gasoline and kerosine (*i.e.*, with a distillation range of about 150–200° C.). It is used as a paint thinner and for dry cleaning, etc. The term " mineral turpentine " is sometimes used for white spirit, but is not recommended, owing to possible confusion with gum turpentine. In the U.S. the term " petroleum spirits " is used for white spirit.